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BOSTON UNIVERSITY
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Thesis

THE ENTITIES WHICH CONSTITUTE THE ATOM

by

William Theron Bryant
(B.S. Colby College, 1934)
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TABLE OF CONTENTS

A. Introduction

1. Review of Advances in Atomic Physics ....Pages 2 - 5

B. The Entities

1. The Electron .... " 6 - 11
    (a) Its Discovery and Subsequent Experiments .... " 6 - 10
    (b) Name and Nature of the Particle .. " 10 - 11
    (c) Mass, Dimensions, and Charge ..... " 11
2. The Potron .... " 12 - 13
    (a) Its Discovery, When and by Whom .. " 12
    (b) Name and Nature of the Particle .. " 12 - 13
    (c) Mass, Dimensions, and Charge ..... " 13
3. The Neutron .... " 14 - 18
    (a) Its Discovery .... " 14
    (b) Detail of Discovery .... " 14 - 15
    (c) The Artificial Production of Neutrons " 16
    (d) Name and Nature of the Particle ... " 16 - 17
    (e) Mass, Dimensions, and Charge ...... " 18
4. The Positron .... " 19 - 26
    (a) Discovery and Details of Discovery " 19 - 22
    (b) Artificial Productions of Positrons " 22
    (c) The Origin of the Positron .... " 22 - 24
    (d) The Ultimate Fate of the Positron . " 24 - 25
    (e) Name and Nature of the Particle ... " 25 - 26
    (f) Mass, Dimensions, and Charge ...... " 26

5. The Neutrino .... Pages 27

(a) Its Discovery .... " 27

(b) Name and Nature of the Particle " 27

C. Conclusion

1. What Next? .... " 28 - 29

D. Bibliography .... " 30 - 32

THE ENTITIES WHICH CONSTITUTE THE ATOM

A. The Introduction.

1. Review of Advances in Atomic Physics

It is remarkable that the man who first noticed that the rubbing of amber would induce in it a new and remarkable state known as the state of "electrification" was also the man who first gave expression to the conviction that there must be some great unifying principle which underlies all phenomena and is capable of making them rationally intelligible; that behind all the apparent variety and change of things there is some primary "something", out of which all things are made and the search for which must be the ultimate aim of all natural science. This double honor goes to Thales of Miletus. As far back as 600 B.C. he first correctly conceived and correctly stated the spirit which has actually guided the development of physics in all ages, and he also first described, though in a crude and imperfect way, the very phenomenon the study of which has already linked together the formerly isolated branches of physics, such as radiant heat, light, magnetism and electricity, and has very recently brought us nearer to this primary "something" than ever before.

It seems to be a native instinct of the human mind to reduce the complexities of the world to the very simplest terms, and to build up the infinite variety of objects which present themselves to the human mind out of different arrangements or motions of the least possible number of elementary substances.

It is certain that the Greeks aimed at nothing less than to banish completely all caprice from nature and ultimately to reduce all of her processes to a rationally intelligent and unified system. And it is also certain that the periods of the greatest advances in the history of physics have been the periods in which this effort has been most active

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and most successful.

The nineteenth century is a period of extraordinary advances. Under Dalton's lead, men for the first time began to get direct, experimental, quantitative proof that the atomic world handed down to us by Leucippus and Democritus and Lucretius, consisting as it did of an infinite number and variety of atoms, was far more complex than it need be, **and** that by the molecular theory the number of necessary elements could be reduced to less than a hundred. The importance of this step is evidenced by the fact that out of it sprang in a very few years the whole science of modern chemistry.

And now the twentieth century, although hardly started, has taken a still bigger and more significant step; it has reduced the primordial entities to four (which are known at present).

The present period is one of most extraordinary and startling development and fertility--"A period in which new viewpoints and indeed wholly new phenomena follow one another so rapidly across the stage of physics that the actors themselves scarcely know what is happening." *

This is especially true in regard to the nature of the atom for--

It was not so long ago
When an atom was so small
It really hardly paid you
To think of one at all.
It was so small that anywhere
An atom safe could be
And pass his time in molecules,
In elemental glee.

---

* Millikan: "The Electron."

It was not so long ago
When an atom was so small
Sage physicists accounted it
The basis of our ball.
And, nothing being smaller,
An atom lived carefree,
Protected from disaster by
Indivisibility.

But now, none calls an atom small--
The lid's thrown open wide.
The world is all agog at what
The atom tried to hide:
Electrons, neutrons, positrons,
Protons. Believe me--
Deutrons, and alpha particles
Within an atom spree!

And "smashing atoms" has become
With thorium 2 C,
A hectic, laboratory game
To play midst their debris,
And now nowhere, in any land,
Can atoms safely rest;
They live, pursued, reclassified,
Divisible--distressed.

This indicates how drastically we have changed our views of the atom. First the atom was considered to be the smallest particle in nature; then it was thought that the atom was composed merely of protons and electrons; and now there are two more particles added to the list, namely, the neutron and the positron. It is my endeavor to depict the nature of these four entities as they are thought to be at the present time.

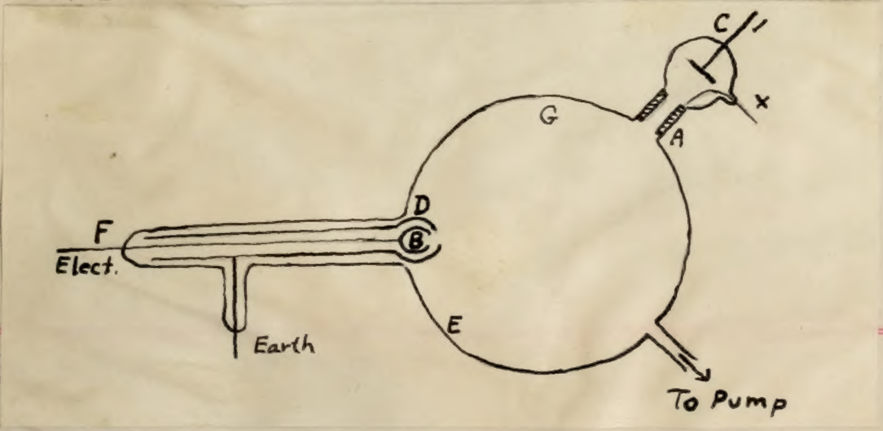
B. The Entities.

1. The Electron.

(a) Its discovery and subsequent experiments

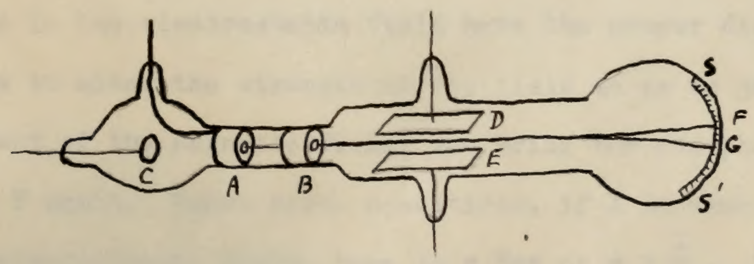
Electrical phenomena have been witnessed since the time of the Greeks but no speculation as to its nature or to the electrical theory date back beyond 1600 and it was not until the time of Benjamin Franklin (1750) that electricity was thought of as granular or atomic. It was not until 1874 that G. Johnstone Stoney clearly stated the atomic theory of electricity. He actually went so far as to estimate the value of the elementary electrical charge, based upon experiments in electrolysis, although he obtained a value much less than the true value.

However, the discovery of the electron is due to J. J. Thomson, of the Cavendish Laboratory, England, in 1895. In experiments made with vacuum tubes as early as 1869, it was noticed that a strange glow appeared around the cathode. Later Sir William Crookes discovered that the rays from the cathode caused fluorescence. J. J. Thomson used a modified Crookes' tube and showed that "corpuscles" , as he called them, were liberated at the negative plate of the tube when bombarded with positive ions and they could be experimentally studied. Perrin showed that these "rays" of corpuscles were deflected by both a magnetic and electrical field in such a manner as to indicate that they were negatively charged. J. J. Thomson used a modification of Perrin's apparatus as shown below and proved conclusively that the corpuscles were negatively charged.



The apparatus consists of a spherical bulb to which is sealed a smaller bulb and a long side tube. The small bulb contains the cathode, C, and the anode, A. The anode consists of a tight-fitting brass plug pierced by a central hole of small diameter. The side tube, which is out of the direct range of the cathode rays, contains two coaxial metallic cylinders, insulated from each other, each being perforated with a narrow transverse slit. One of these, D, is grounded; B is connected with an electrometer by means of the rod, F. When the tube is pumped down to the proper pressure for the production of cathode rays, a phosphorescent spot, E, will appear directly opposite the cathode, C. Upon testing B for possible electrification by means of the electrometer it is found to be uncharged. When the cathode stream is deflected by means of a magnet so that the rays fall on B, a sudden charging of the electrometer is observed, proving that B is becoming electrified. Upon deflecting the rays still further, so that they are no longer incident on B, the accumulation of the charge immediately ceases. When the electrometer is tested for polarity, it is found to be negatively charged, thus proving that the charge carried by the cathode rays is negative.

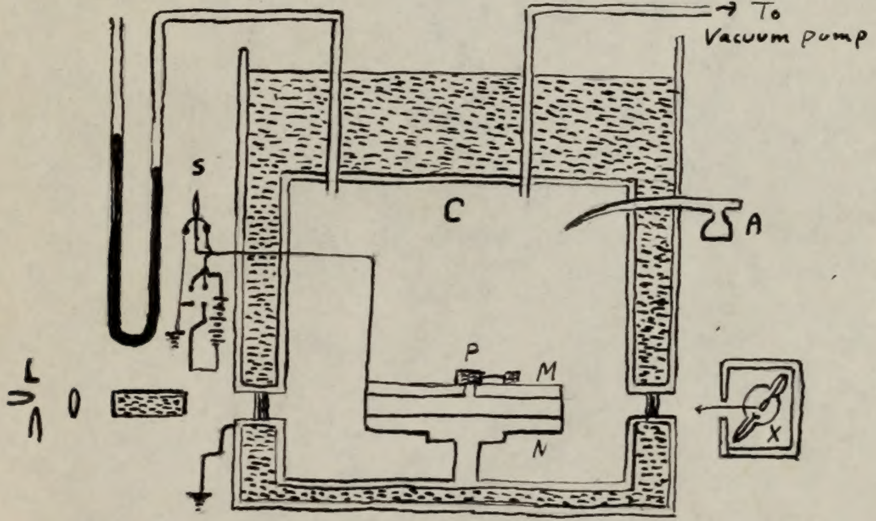
J. J. Thomson also determined the velocity of the cathode particles. To compute the ratio of the mass of the particle to its charge, he devised a special tube as shown below.



It consists of a glass tube about 60 cm. in length, furnished with a flat circular cathode, C, and an anode, A, in the form of a cylindrical brass plug about 2.5 cm. long, pierced by a central hole 1 mm. in diameter. Another brass plug, B, is placed about 5 cm. away from A, the two holes being in exactly the same straight line, so that a very narrow bundle of rays may pass along the axis of the tube and fall on the phosphorescent screen at the opposite end of the tube. On the screen is a milli-meter scale ss'. Two parallel plates, D, and E, are sealed into the tube for the purpose of establishing an electric field. When the tube is connected to an induction coil, or other source of high-potential, a phosphorescent spot appears at F. If a strong magnetic field is applied, the line of force being at right angles to the plane of the diagram, the rays will be deflected vertically, and the spot on the screen will move from F to G. Let H denote the strength of the magnetic field, and m, e, and v represent the mass, charge, and velocity respectively of the particles. A magnetic field of force H, acting at right angles to the line of flight of the particles will exert a force, Hev, which will tend to deflect the particles from a rectilinear path. This force must be equal to the centrifugal force of the moving particle acting outwards along its radius of curvature. Therefore $Hev = \frac{mv^2}{r}$ or $Hr = \frac{mv}{e}$. Since both H and r can be measured, the ratio $\frac{mv}{e}$ can be determined. Now if a difference of potential is established between D and E, and the lines of force in the electrostatic field have the proper direction, it is possible to alter the strength of the field so as to just counter-balance the effect of the magnetic field, and bring the phosphorescent spot back to F again. Under these conditions, if X denotes the strength of the electrostatic field, then $Xe = Hev$ or $v = \frac{X}{H}$. Since both

H and X can be measured, v can be calculated and, by introducing the value so obtained into the ratio mv/e, the ratio m/e can be evaluated.

Many early attempts were made to determine the charge, e,of an electron, notably those by Townsend (1897), Thomson (1898), and H. A. Wilson (1903). During the years 1906-1916, R. A. Millikan modified and greatly improved their methods and evolved an apparatus of great precision. A simplified diagram of Millikan's apparatus is shown.



A finely divided spray of oil is introduced into the chamber, C, by means of the atomizer, A, until one of the tiny drops finds its way through the aperture P, into the space between two condenser plates M and N. The hole P is then closed and the air between the plates is ionized by means of the X-ray tube, X. The arc lamp, L, serves to illuminate the drop and its motion is observed through a microscope not shown in the diagram. The eye-piece of the microscope is fitted with an engraved glass scale which enables the observer to measure accurately the motion of the drop. When one of the ions in the air collides with the drop in the condenser chamber, it acquires an electric charge, the sign of which will determine the subsequent direction of its motion with

reference to M and N. By means of the switch, S, the signs of the charges on the two plates can be reversed, thus causing a corresponding reversal of the direction of the drop. By careful adjustment of the potential between the plates, it is possible to keep the drop in the field of view during an entire experiment. Any change in the speed of the drop is an indication of a change in the charge which it carries; therefore, since the speed with which the drop moves is directly proportional to the magnitude of its charge, it follows that, by measuring the change of speed and comparing it with the drop when falling due to gravitational force alone, the value of the charge carried by the drop can be calculated. Millikan observed that several electronic charges were quite commonly acquired by a single drop, but in every case the total charge was invariably an exact integral multiple of the elementary charge, e. Every conceivable correction has been applied and Millikan's value is believed to be in error by less than 0.1 percent.

I have personally performed this experiment and obtained a value of e which was about 2 percent larger than Millikan's value. It is a beautiful experiment.

(b) Name and Nature of the particle

The word "Electron" is the Greek word for amber and was suggested as a name for the natural unit of electricity by G. Johnstone Stoney in 1891. It was introduced to denote simply a definite elementary quantity of electricity without any reference to the mass or inertia which may be associated with it.

Electrons are invisible,negatively charged particles. They are deflected by a magnetic or electric field, cast a shadow, cause fluorescence and phosphorescence and generate heat in any substance

they strike. The electron is the key to all chemical reactions.

While single electrons behave like particles it has been found that an aggregation of them has the properties of waves and they can be deflected from the surfaces of nickel crystals. The first experiments to show this wave phenomenon were carried out by Davisson and Germer in 1925. Later investigation and study showed that their behavior is sufficiently comparable with that of X-rays to show that they exhibit the properties of waves.

(c) Mass, dimensions, and charge.

The mass of the electron is equal to 1/1839±1 of the mass of the hydrogen atom or more specificly, it is equal to $(9.035 \pm .010) \times 10^{-28}$ gm. Of course this value is the rest mass, or the mass of the electron moving with a velocity slow compared with that of light. The mass increases with the velocity according to the Lorentz equation $m = m_0 / \sqrt{1 - \frac{v^2}{c^2}}$ where m_0 = rest mass; c = the velocity of light and m is the mass when it is moving at a velocity v. Electrons have been made to move with a velocity of about 140,000 miles per second which results in an appreciable increase of mass.

Its radius is 1/50,000 the radius of the atom or 2×10^{-13} cm. The charge as determined by Millikan is $(4.770 \pm .005) \times 10^{-10}$ e.s.u.

2. The Proton.

(a) Its discovery, when and by whom.

Our physical knowledge of the proton is not nearly as complete as that of the electron. For some time after the discovery of the electron nothing definite was known about the positive unit of electricity. Discoveries in connection with radio-active phenomena suggested that perhaps the charge on the nucleus of the hydrogen atom might be taken as the ultimate positive unit.

In 1909, Geiger and Marsden, acting on the suggestion of Rutherford, performed some experiments on the passage of alpha particles through metal foils. A fluorescent screen was used to detect the alpha particles after they passed through the metal. It was found that the particles tended to be deviated slightly outward from the straight path and a few were deflected as much as 150°. This was too large an angle to be explained by the law of chance. They also found that the deflection increased with the atomic weight of the metal. It was therefore assumed that some great force, due to a large concentrated mass, must be present at certain points.

Later experiments showed that, when atoms of nitrogen were bombarded with alpha particles, the hydrogen nucleus, of which the nitrogen was formed, was thrown forward. It was shown that hydrogen nuclei are to be found in all other nuclei. Rutherford suggested that the hydrogen nucleus be taken for the ultimate unit of positive electricity, for up to that time physicists had been unable to discover a positively charged particle of mass less than that of the hydrogen nucleus. Neither had they been able to separate the positive charge from the particle nor had they discovered a smaller positive charge.

(b) Name and nature of the particle.

The name proton from the Greek πρῶτον, first,--the primary substance,

was suggested for it by Sir Ernest Rutherford at the Cardiff meeting of the British Association in 1920. The charge of the proton is equal and opposite to that of the electron. It is much smaller than the electron and their relative magnitudes may be appreciated from the following. If we suppose that the hydrogen atom, which is composed of an electron revolving around a proton, were magnified until its diameter was three hundred miles, then the electron would be represented by a balloon sixty feet in diameter revolving around the proton the size of a marble. If the balloon weighed one thousand pounds, the marble would weigh about one thousand tons. The proton is considered to be a constituent of all atomic nuclei and the masses of these nuclei are due mostly to the protons contained therein.

(c) Mass, dimensions, and charge.

The mass of the proton has been measured directly in the free state and is practically identical with that of the neutral atom of hydrogen or $(1.6608 \pm .007) \times 10^{-24}$ gm. The radius was found to be $1/1838 \pm 1$ that of the electron. Its charge is the same as that of the electron but is opposite in sign.

3. The Neutron.

(a) Its discovery.

The neutron was discovered early in 1932 in the rays sent off by the light element Beryllium when a piece of this material was bombarded by helium atoms flying at about 9000 miles per second. The experiments were carried out by Irene Curie Joliot, and M. Joliot, but the rays were first recognized as neutrons by Chadwick of Cambridge, England.

It was indicated as early as 1915,by a curious arithmetical discrepancy, that the nucleus of an atom of Beryllium contained a neutron. Not only was the neutron's existance predicted but also its mass and properties were given on April 12, 1920 by Harkins and on June 3, 1920 by Rutherford, both of whom assumed the neutron to be one of the fundamental particles of atomic structure.

Probably one reason why the neutron was not discovered sooner is due to the fact that it does not produce a track in the cloud chamber.

(b) Details of the discovery.

The first step leading to the discovery of the neutron was taken by Bothe and Becker at Giesen, Germany, when they found that if certain light elements, notably Beryllium, are bombarded with alpha rays of polonium they emit rays of several times the penetrating power of the most energetic gamma rays from known radio-active substances. They used Geiger counters to detect the rays and to estimate the value of their penetrating power. They interpreted their experiments as the bringing to light of gamma rays of an energy of as much as 14 million electron-volts, and they accounted for the high energy by assuming that the alpha particle was captured by the nucleus of the bombarded atom of Beryllium and that the energy emitted in the radiant form came from the known excess in the mass of Be + He over that of the atom assumed to be produced by

their union. They merely adopted the atom-building hypothesis and then used Einstein's energy equation $E = mc^2$ to supply the necessary energy.

The second important advance was made by Curie and Joliot, in Paris. They repeated the experiments and found that if they inserted in the path of the rays to the chamber sheets of carbon, aluminum, copper, silver, and lead, the ionization currents in the electroscope were practically unaffected, but that when they interposed a sheet of paraffin, the current was doubled. Similar, though smaller, increases were observed when water, cellophane, or other substances containing hydrogen were used in place of paraffin. They then showed that this increase in current was due to the fact that Bothe's rays in passing through hydrogen compounds knocked out of them protons or hydrogen nuclei. They thought they had shown by these experiments that electromagnetic rays of high frequency are capable of imparting high kinetic energies to the nuclei of hydrogen and other light atoms. But such a transfer of momentum and energy from a photon of the energy in question to a proton or other nucleus is impossible without a violation of the laws of momentum and energy that have been found to hold everywhere thus far.

It was Chadwick who solved the difficulty by showing that the principle of the conservation of momentum could be retained and that the momenta all came out consistantly for the various types of nuclei to which motion was imparted by Bothe rays if a non-ionizing particle of the mass of a proton were the bombarding agent. In other words, he brought forward convincing evidence that when the alpha particles from polonium bombarded atoms of Beryllium, or similar atoms, they knock out of the nuclei of these atoms particles of about the mass of the proton but devoid of charge.

(c) The artificial production of neutrons.

Soon after the neutron was discovered, scientists looked for a means of producing the particle artificially and in large numbers so that its properties could be studied. Crane, Soltan, and Lauritsen found a suitable method. They used two porcelain vacuum tubes, one above the other, with a passage between for the ions to pass through. A one million volt cascade transformer was used as a source of potential and the middle point between the tubes was connected to the half potential point of this apparatus. The ions which were produced at the inner electrode of the upper tube were accelerated successively in each tube through one half the total potential. Electrons which might arrive on the reverse half cycle were removed by applying a magnetic field to the ion beam. The resulting beam was allowed to strike a two inch target made of brass, one side of which was covered with Beryllium and which could be rotated by a shaft to expose either the brass or the Beryllium. The walls of the electroscope, which was used to detect the neutrons, were lined with paraffin and the whole electroscope was inclosed in a lead cylinder. The neutrons were supposed to penetrate the lead wall and eject hydrogen ions into the electroscope from the paraffin walls. The results with this apparatus were very satisfactory.

(d) Name and nature of the particle.

Since the newly discovered particle was neutral in charge it was natural to call it the neutron. Since the neutron is electrically neutral it produces no tracks in a cloud chamber. It is believed that the neutron is composed of a proton and an electron bound very closely together. It is therefore essentially a hydrogen atom in its content but the volume is very much less. Not only is the volume exceedingly less but the mass of the neutron is also somewhat less then that of a hydrogen atom.

If the neutron is really composed of an electron and a proton bound

very closely together, it would not be a true elementary particle but a very stable combination of two elementary particles already known. Various theories have been advanced as to how the two particles are joined together. American scientists seem to think that the neutron is made up of a positively charged nucleus, a proton, plus a negatively charged electron, while German scientists contend that it may consist of a central negatively charged core and a positively charged electron. It also has been suggested that the neutron may be a more fundamental neutral particle, which, when combined with a positron, becomes a proton. However, at present the known facts seem to be more in accord with the idea that it consists of a proton and an electron.

The possible great significance of the neutron is emphasized by the rapidly growing idea that all atomic nuclei consist merely of neutrons and protons. This possibility was indicated about ten years ago in connection with a formula developed both by Masson and by Harkins. The idea that this formula represents the constitution of all atomic nuclei has been developed into a theory by Heisenberg. The most important relations which are apparent are: in general one proton, but not more than one, unites with a single neutron; almost all neutrons in atomic nuclei exist in the form of pairs; and almost all light nuclei are built up from helium nuclei, which may be formed from neutrons and protons.

"While before the discovery of the neutron there were facts which seemed to a few to indicate that such a particle should exist, the discovery of its existance and of the fact that it adds itself to other nuclei will have, in the next few years, a remarkable influence not only upon the science of the constitution of matter but also upon that related philosophy which has become so influential during the last half decade." *

---

* W. D. Harkins, Scientific Monthly Vol. 36.

(e) Mass, dimensions, and charge.

The mass of the neutron is considered by Chadwick to be above 1.003 and probably lies between 1.003 and 1.008. He gives the most probable value, determined by bombardment of boron by alpha-particles, as 1.0067. The validity of this value rests in the assumption that gamma-rays are not emitted in the process. Curie and Joliot give a much higher value, 1.012, and Lawrence and others a much lower one, 1.0002. It is suggested that the value 1.006 be accepted for the mass of the neutron until more accurate positive-ray work is done.

The radius of the neutron has been estimated to be about 1.4×10^{-13} cm. The energy as computed from Einstein's equation, $E=mc^2$, is about 5×10^5 electron-volts.

The neutron has no detectable electrical charge.

4. The Positron.

(a) Discovery and details of the discovery.

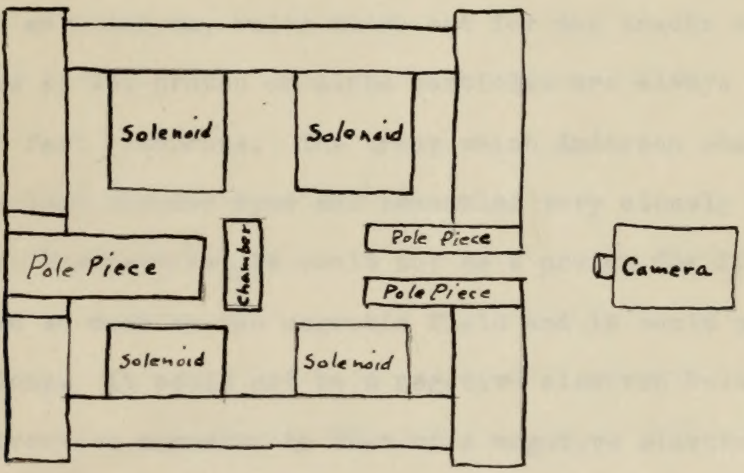
The negative electron has been known for about 40 years but it was taken for granted that a particle similar to it but with a positive charge never appears in nature or in atomic structure unless it has a mass of more than a thousand times as great as the negative electron. However, three years ago Dirac was led by his theoretical work to postulate the existence of a positive electron. No one had the least ideas as to how it was to be found or by what means it could be produced. It remained to be discovered in an "accidental" manner, as so many of the scientific discoveries have been made, during researches otherwise intended. Its discovery took place on August 2, 1932 during the study of cosmic rays by Dr. Carl D. Anderson of the California Institute of Technology.

C. D. Anderson was in the course of a cosmic-ray research in which he was using the expansion chanber of C. T. R. Wilson to observe the paths of ionizing particles belonging to these rays. He was not the first to use this method of observing the long straight tracks which these particles make, Skobelzyn's name being the first to be mentioned in this connection. It had also been previously noticed that in a moderate magnetic field these tracks are either very slightly curved or not sensibly curved at all, so that the particles which make them must be moving very rapidly. But Anderson was not satisfied with the usual method and accordingly made two very important changes.

Previously, the expansion chamber had been set up with its axis vertical and its breadth horizontal. But the ionizing particle of the cosmic rays move mostly in a direction close to the vertical, which was a rather inconvenient way of observing them. Anderson therefore turned

the whole apparatus on its side, so that the breadth of the chamber lay in a vertical plane, and this has become the modern practice in cosmic ray research.

The second and most radical change was the insertion of a lead plate of 6mm. thickness in the chamber. The essential features of his apparatus are here shown.



Some of the ionizing particles of the cosmic rays have a momentum sufficiently great to pierce the lead plate with no measurable deflection and very often their speed is so great that they suffer no deflection on either side of the chamber in a strong magnetic field. Anderson used a chamber 15 cm. broad and used a field of 15000 gauss, an arrangement which is exceptionable both for strength and extensiveness of field. Occassionly he observed a track that was more strongly curved on one side of the plate than on the other. The corpuscle making the track must have been going from the side where the curvature is less and the speed consequently greater, to the side where the curvature is greater and the speed proportionately less. Otherwise it would have to be assumed that the corpuscle had gained energy to the extent of tens of millions of electron volts in passing thru the lead. This would have been contrary to the law of the conservation of energy.

Therefore the direction of the corpuscle in describing the path is fixed and the observer can tell whether the corpuscle is positive or negative.

After many attempts, Anderson operated his expansion chamber at exactly the right moment and obtained the track of a positive particle. One might ask why this is so significant for it might be a proton or alpha particle. But the character of the track, which is long and narrow and resembles that of an electron, rules these out for the tracks of such massive particles as the proton or alpha particles are always much thicker than those of fast electrons. The track which Anderson observed was definitely of the long slender type and resembled very closely the track of an electron. Furthermore, it could not be a proton for it would not be deflected so much by the magnetic field and it would not have been nearly so long. It could not be a negative electron because it was deflected in a direction opposite to that of a negative electron, showing that the particle was positive in charge. Here then must be the positive electron.

Meanwhile in the Cavendish Laboratory, Blackett and Occhialini were studying cosmic rays with an expansion chamber lying on its side. In order to increase the chance of getting a photograph of the tracks they made use of a pair of Geiger Counters, one on each side of the chamber, and a mechanism so contrived that the chamber would expand when and only when both the counters should react at nearly the same instant. They obtained several photographs showing many tracks, all radiating from a single point, and they called this burst of tracks "A shower". These photographs showed tracks similar to those made by electrons, some curving in one direction and some in the opposite. This might mean that some negative electrons are shooting out from the point and others shooting in. But this did not seem to be possible so it was

concluded that both positive and negative electrons were radiated from the point.

In the spring of 1932, M. F. Joliot and Mme. Joliot (Irene Curie) in the Institut du Radium in Paris, were engaged in photographing tracks which occurred from the radiations of Po and Be. They likewise observed that there were paths of opposite curvature. They explained this by saying that electrons were coming into the point from the outside. However they later helped to prove the existence of the positive electron.

(b) Artificial production of positrons.

Chadwick, Blackett, and Occhialini were the first to produce positive electrons artificially. Just outside the wall of the Wilson Chamber they placed a piece of beryllium exposed to the constant bombardment of alpha-rays of polonium. This is a source of both neutrons and high-frequency photons and is denoted by "Po + Be". A piece of lead was placed just inside the chamber and when the neutrons and photons impinged on the lead they produced cloud tracks which had the specific appearance of electron tracks, some deflected in one direction and some in the other.

This very same phonomenon was observed a short time later by Meitner and Philipp in Dahlem. They had the source "Po + Be" within the chamber and enclosed it in a brass capsule which performed the same function as the lead plate.

(c) The origin of the positron.

The question then arose as to the origin of the positron--is it produced by the photons or the neutrons ejected from the "Po + Be" source? One might say that the neutron is responsible since this is a new particle and the photon has been known for some time, but this is wrong.

Curie and Joliot showed that the number of positrons ejected depends more on the photon than the neutrons, by cutting out first one and then the other. Another fact which shows that photons are responsible is that positrons can be generated by streams of gamma-rays--high energy photons--coming from radio-active bodies which do not emit any detectable number of neutrons.

Now a very natural question arises as to how a photon produces the positron. Dr. K. K. Darrow says: "The positive electron comes into being by virtue of a transmutation more drastic and amazing than any hitherto effected or imagined: it is supposed that a photon transmutes itself into a pair of electrons, one of each sign."*

If the above happens, such a transmutation leaves the net charge of the universe unchanged. If the net energy of the universe is to be unchanged, the principle of the equivalence of energy and mass must be taken into account which is given by Einstein's equation $E = mc^2$, where E is the energy, m the mass and c the speed of light in vacuo. According to this relation the masses of two electrons, when transmuted into units of energy amount to about one million electron volts. The remaining energy of the photon--its original energy minus this million--might go into kinetic energy of the electrons, or into a new photon, or divide itself between these forms. If this central idea is correct then positive and negative electrons should be liberated in pairs and the energy of each pair should never come within a million volts of the energy of the primary photon.

As a matter of fact positive and negative electrons are emitted in pairs. There are exceptions to this which may be explained by saying that probably the associated negative got caught in the metal. Experimental evidence further shows that the kinetic energy of an electron

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* Scientific Monthly, Vol. 38.

pair or of an isolated positive never comes within a million volts of that of the primary photon and no exceptions have ever been found.

Thus in this imagined process of transmutation, charge and energy are conserved in conformity with two familiar principles. But there is still a third principle of conservation, older than either; it is Newton's third law, that the total momentum of the world ought to remain invariable. But when it is attempted to apply this principle a perturbing conclusion is reached, namely that: if a photon in the depths of space should spontaneously transmute itself into two electrons, both momentum and energy could not be preserved. This is easily seen because if it is considered that energy and momentum are both conserved then the speed of at least one of the electrons is greater than that of light, which is contrary to the theory of relativity on which the calculation is based, and therefore a reductio ad absurdum. However, this difficulty has been overcome by suggesting that the nucleus of some atom enters into the process, to the extent of receiving enough momentum to balance the system; and inversely that the process cannot take place unless there is a nearby atom available to serve this purpose. The fully developed theory introduces an atom to perform this function.

Now that it is known how positrons are formed scientists, notably Joliot and also Thibaud, have been able to increase the rate of production from three or four a year to thirty thousand in a second, which is a remarkable advance in so short a period of time.

(d) The ultimate fate of the positron.

From the time the positron was first discovered, the question as to what became of it has been a subject of long discussion. It is certain that a free positron cannot live very long after its energy of projection has been spent. Experiments show that the positron plays no part in

conduction--gaseous, electrolytic, or metallic--and hence that it does not remain free. Theory, on the other hand, said that free positrons and electrons existing side by side would of necessity rush together and destroy each other unless in some way through the presence of the free positron a new proton could be formed which by then capturing **from** the surroundings a new electron would give rise to a new atom of hydrogen. In all nuclei the mutual destruction of positive and negative electricity is avoided by the usual quantum conditions holding within the atom. But regardless of how the positron disappears, the region in which such disappearances are taking place must be a region from which radiant energy is emerging, for with either alternative as to mode of escape, according to Einstein's equation, the disappearing potential energy of two separated attracting systems, corresponding to the m in $E=mc^2$, must of necessity appear in radiant form.

Experiments performed by Lauritsen and Crane have fairly well established the theory that the positron lives outside the nucleus only until it has lost the greater part of the kinetic energy that has been imparted to it--this will perhaps be of the order of 5×10^{-10} seconds--when it disappears somewhere probably "by committing suicide with the first negative that comes near it."*

(e) Name and Nature of the particle.

Since the new particle resembles the electron in everything but the charge, which is equal but opposite, it was natural to call it the positive electron. For convenience, it has been shortened and is now called the positron.

It has been proved from the curvature of its path that the positron has a positive charge and that it is deflected from a straight path by a magnetic or electric field. It is evident also that the particle is much

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* Millikan: "Electrons (+ and -), Protons, Photons, Neutrons, and Cosmic Rays"

smaller than the proton or alpha particle because the tracks are thinner and longer than those formed by either of the other two particles. It has been shown that the positron is formed simultaneously with an electron by a photon. In short it is very much like an electron in everything but sign of the charge.

(f) Mass, dimensions and charge.

Since the life of the positron is so short it is very difficult to carry out experiments upon it. Attempts have been made to estimate the charge and mass from the length and appearance of the track but there is a question as to how accurate these estimates are. Thibaud succeeded in applying one of the classical deflection methods of measuring the charge to mass ratio, which is not accurate. He published the statement that the value of this ratio is of the same order as that for the electron. It is almost certain that the value for the positron is between one half and twice, and between one tenth and ten times that for the electron. However, it is very likely that eventually there will be an accurate value for this ratio for the positron as well as the electron.

5. The Neutrino.

(a) Its discovery

The existance of the neutrino has not yet been proved and it is rather unlikely that it will be for some time, at least by any method known to the physicist at present. The reasons for this are that it produces very minute ionization, about one ion in a path of 150 km. in air at normal temperature and pressure, and any reaction with nuclei must be extremely small.

(b) Name and Nature of the particle.

The name "neutrino" comes from the Italian, and was suggested by Professor E. Fermi. Although the existance of the neutrino has not yet been proved, science has predicted some of its properties. It would be an electrically neutral particle like the much larger particle, the neutron, but would weigh only about as much as an electron. Physicists predict that like most atomic particles it would spin on its axis like the earth, and it might spin either clock-wise or counter-clock-wise. It is believed that the neutrino has a twin, called the anti-neutrino, which spins in a direction opposite to the neutrino. The spin of these twins would make it possible to account for some of the mysterious magnetic properties in atoms.

An entity which it is practically impossible to detect is a very attractive fiction. However, it is at least a very convenient way of expressing our difficulties concerning conservation--wrapping them up in one package, as it were. "The neutrino may be likened to one of the face-saving formulae so popular with our statesmen: it may not solve the problem, but with a new word it stops troublesome questions for the time being." *

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* Andrade: "Nature" September 8, 1934.

C. Conclusion.

1. What next?

This is a question which time and time alone can answer. Startling discoveries have followed one another so rapidly that theory has been unable to keep up the terrific pace. It has been remarked that science should take a 10 year holiday so that the rest of the world might catch up, but the scientist has no intention of stopping even for an instant. In fact the scientist strives more feverishly than ever before to discover the secrets which nature has withheld for so long.

We have just seen in review what are believed to be the fundamental entities of the atom. But are they the primordial elements of our universe? There seems to be some doubt as to the correct answer to this question, for it is not in keeping with the method of modern science to make any dogmatic assertion as to the ultimateness of the known atomic entities.

Evidence has been brought forward by Ehrenhaft to show that the charge on the electron is divisible. He based his conclusion on the results of experiments with oil drops, and a method of determining e "from the Brownian movement." He contends that the value of the smallest charge which can be caught from the air actually is a function of the radius of the drop on which it is caught, being smaller for small drops than for large ones. However, Millikan has since done work similar to Ehrenhaft's experiments and is convinced that there is no evidence whatsoever to support the theory of a sub-electron.

Now that a positive charge has been found which is associated with a mass much less than that of a proton, one wonders if the positive charge can be separated from the proton and if so what would be left of the proton after the charge is detached. Would it be a neutron or what?

This raises the question as to the exact nature of the neutron. Is it composed of a proton and an electron or is it composed of a negative proton and a positron or is it altogether different from either of the above combinations?

These are only a few of the many questions which the physicist will attempt to answer in the future. If progress continues as rapidly as it has in the last two or three years we may expect that at least some of these questions will be answered in the near future. For with the invention of such elaborate apparatus for attacking the nuclei of atoms, whole new fields of possibilities have been opened up to the scientist.

What the future has in store for us is impossible to predict. At least we feel quite certain that the future will bring forth fantastic and thrilling discoveries, which will challenge the imagination of the scientific world.

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